



1 INTRODUCTION

Plantar pressure distribution provides significant information for clinicians and researchers about the structure and function of the foot, general mechanics of gait and is a helpful means to evaluate patients with foot complaints.

Image registration, the process of optimally aligning homologous structures represented in images, can be very useful for clinicians and researchers, since tasks such as identification of the main plantar pressure areas and classification of the foot type can be done automatically. Image registration also allows that clinicians accurately compare the plantar pressure of a patient over the time or with a database. In addition, pedobarographic image registration supports pixel-level statistics, which makes possible the extraction of biomechanically-relevant information from plantar pressure images more effectively than traditional regional techniques.

In this work, we make a comparison among two recent image registration methods: one based on the matching of the external contours' points of the feet and another one based on the maximization of the cross-correlation between pixels' intensity. We assessed the accuracy of both by using two image similarity measures: exclusive or (XOR) and mean squared error (MSE).

2 RELATED WORKS

Several methods had been developed to register pedobarographic images, for instance, principal axes (Fig. 1), modal matching (Fig. 2, Fig. 3) and optimization based methodologies.

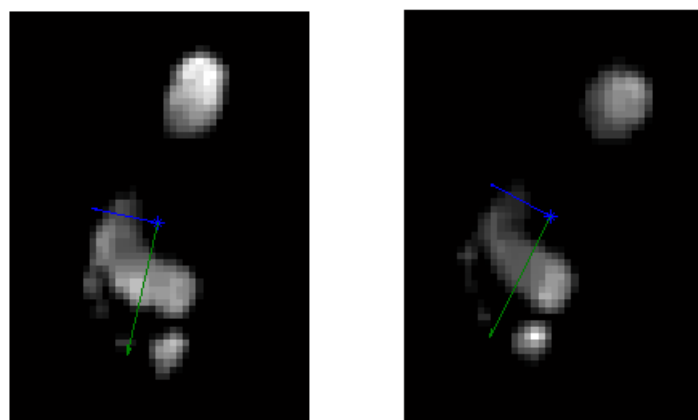


Fig. 1: Two pedobarographic images and the representation of their centroids and principal axes.



Fig. 2: On the left, plantar isobaric contours; on the right, the correspondences found between two isobaric contours based on modal matching (Tavares et al., 2000).

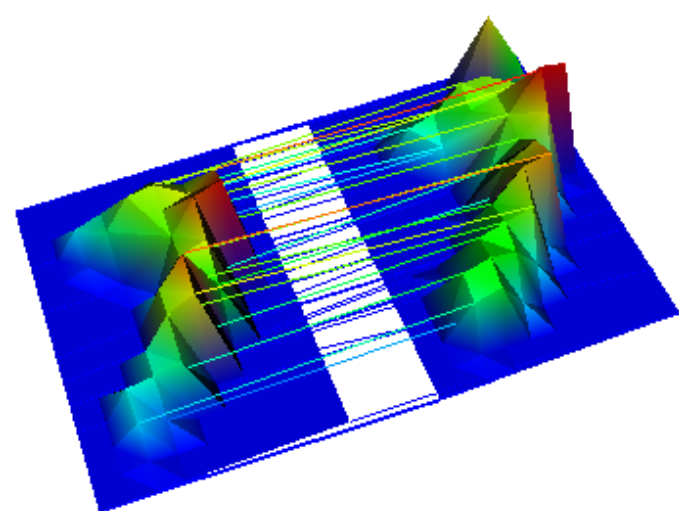


Fig. 3: Correspondences found between two surfaces by finite elements and modal matching (Tavares et al., 2000).

3 METHODS PROPOSED

2.1 Contours-based method

The contours-based method can be described in four steps (Fig. 4): (1) extract the external ordered contours of the feet, (2) assemble the contours' affinity matrix based on geometric features, (3) determine the matching of the contours' points using an optimization algorithm based on dynamic programming and with ordering preserving constraint, and (4) compute the geometric transformation parameters based on the matching found (Oliveira et al., 2009).

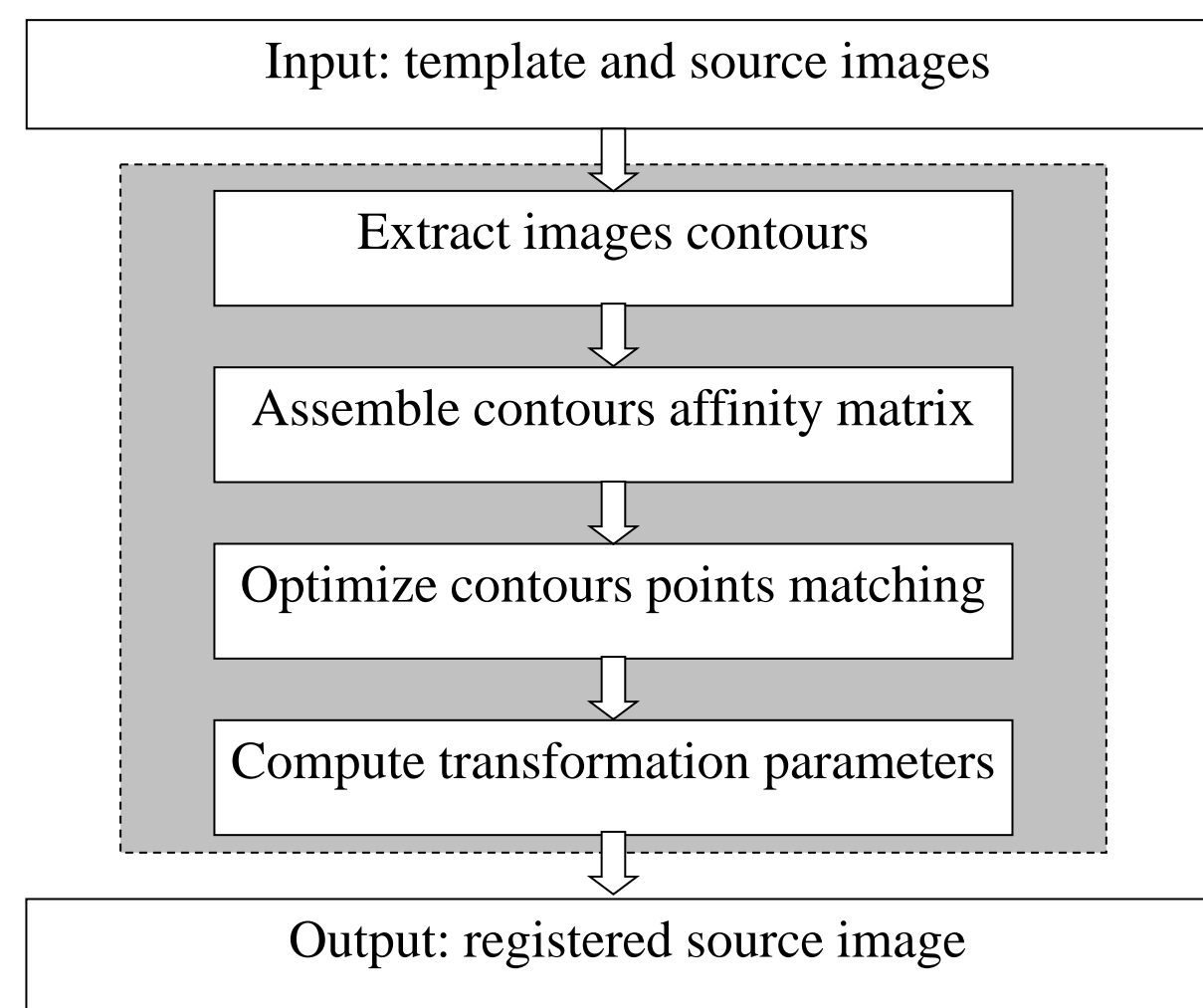


Fig. 4: Method followed to register and compare template and source images based on image contours.

2.2 Cross-correlation-based method

The assumption behind the cross-correlation-based method is that two images are optimally registered when their cross-correlation is maximized.

If one considers two discrete function f and g , in particular two images, and their cross-correlation:

$$CC_{fg} = \sum_i f(i)g(i)$$

then, the cross-correlation can be given in function of a shift a by:

$$CC_{fg}(a) = \sum_i f(i)g(i-a)$$

This equation can be written as a convolution:

$$CC_{fg}(a) = \sum_i f(i)g(i-a) = \sum_i f(i)\bar{g}(a-i) = \{f * \bar{g}\}(a)$$

where $\bar{g}(x) = g(-x)$ and $*$ represents the convolution. From the convolution theorem, one can obtain:

$$\mathbf{F}\{f * \bar{g}\} = k \cdot \mathbf{F}\{f\} \cdot \mathbf{F}\{\bar{g}\}$$

where \mathbf{F} represents the Fourier transform and k is a constant that depends on the specific Fourier transform normalization.

Thus, computing the inverse of the Fourier transform of the product of the last equation, the cross-correlation can be obtained for all shifts. Then, the coordinates of the point which has the higher value represent the desired optimal integer shift.

Based on the Fourier transform properties and converting the image spectrums to log-polar coordinates systems, we also can obtain the rotation angle and global scaling. Fig. 5 display a diagram of this approach (Oliveira et al., 2010).

4 RESULTS

Some experimental results are indicated in Table 1, which were obtained from 30 pairs of peak pressure data sets. The assessment done was based on two similarity measures: the exclusive or (XOR) and the mean squared error (MSE). As lower are the values of these measures, better registered the images are. Additionally, the processing time was considered.

5 CONCLUSIONS

The experimental results validate the contours-based and cross-correlation-based methods. The first one revealed to be more suitable to register the image shapes, and the second one to align the image intensities. The contours-based method reached the best XOR accuracy, and the cross-correlation method reached almost equal accuracy than the best result reported so far. Both methods required very low computational processing times, even when running on a common notebook PC. Thus, the accuracy and computational speed of these methods allow their utilization in "real-time applications".

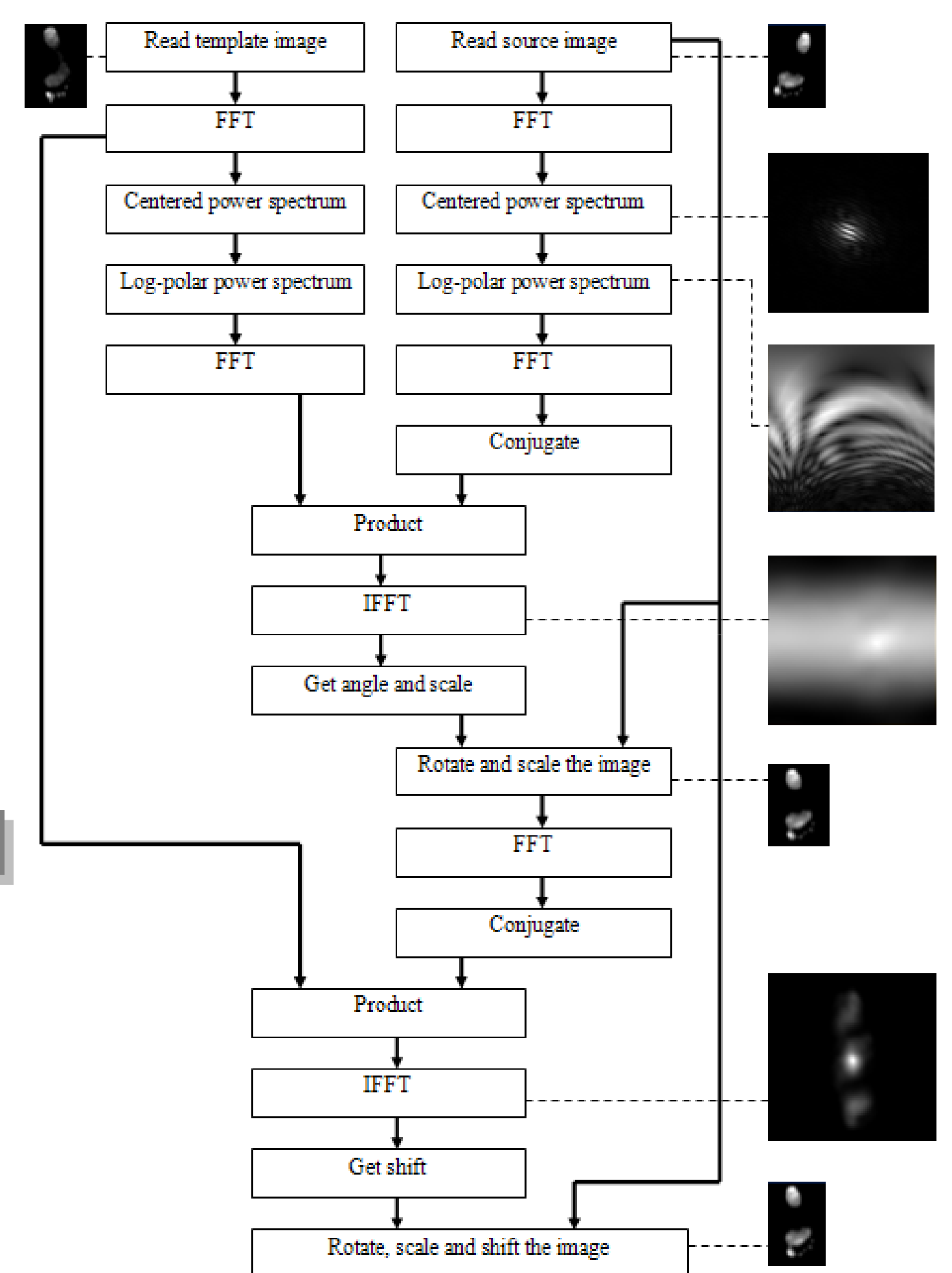


Fig. 5: Algorithm of the cross-correlation method and the data pipeline.

Table 1: Comparison in terms of registration accuracy, considering XOR and MSE as similarity measures, and speed.

METHOD AND PARAMETERS	MSE		XOR		Time
	[N/cm ²] ²	SD	%	SD	[s]
Before Registration	23.6	22.8	17.9	7.92	
Principal axes* (pressure images)	8.71	10.1	14.4	3.51	0.10
Principal axes* (binary images)	7.02	6.29	13.4	2.73	0.11
Contours-based (just geometric approach) (Oliveira et al., 2009)	5.80	3.07	11.7	2.63	0.025
Contours-based (with pseudo-optimization) (Oliveira et al., 2009)	4.52	2.32	11.1	2.52	0.053
Cross-correlation-based (Oliveira et al., 2010)	4.06	2.11	12.3	1.73	0.033
REFERENCE RESULTS					
Min(MSE)*# (Pataky et al., 2008)	3.98	2.09	12.5	1.78	9.01
Min(XOR)*# (Pataky et al., 2008)	5.45	3.29	11.6	1.73	9.00

*Implemented in Matlab. #Using optimization models based on evolutionary algorithms.

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